NOAA Technical Memorandum NMFS

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NOAA-TM-NMFS-SWFC-22

October 1982

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Center

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Malcolm Baldrige, Secretary
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ABSTRACT

A modern adaptation of an old fishing technique is gaining recognition in the Pacific and elsewhere as an effective means to increase fishing productivity in the open sea. The use of man-made, free floating, and anchored floating devices to aggregate pelagic fishes for subsistence, recreational, and commercial fishing has increased markedly in recent years; estimates of deployed and planned units exceed 1,000. These devices have been anchored in depths ranging from several hundred to several thousand fathoms. This report reviews the development and present use of fish aggregating devices in the Pacific and Indian Oceans.

INTRODUCTION

Possibly the most dramatic change in coastal and open-ocean fisheries in recent years in the central and western Pacific and Indian Oceans has been the use of the fish aggregating device (FAD). The development of man-made FAD's has evolved naturally from the phenomenon of fish being closely associated with drifting objects such as logs, algae, and other flotsam (Uda 1933; Kojima 1960; Hunter and Mitchell 1967; Inoue et al. 1968) and stationary objects such as offshore drilling platforms (Hastings et al. 1976; Dugas et al. 1979). The use of FAD's for large-scale commercial fishing was first developed in the Philippines about 5 years ago (Chikuni 1978). By 1979 well over 600 FAD's were being used in the calm waters of the Sulu Sea and Moro Gulf.[1] Since 1979 the utilization of man-made FAD's has spread to many island countries in the central and South Pacific and Indian Oceans. To date more than 300 have been deployed.

The growth in the popularity of FAD's has been due to their success in attracting fish in large numbers, thereby affecting all levels of fishing. The artisanal or subsistence level fishermen not only were able to increase their catches but were assured of making catches daily, commercial fishermen were able to increase their catches substantially, and recreational fishermen were able to reduce no-catch trips. The FAD's also enabled all motor-driven vessels to reduce fuel consumption considerably by eliminating unproductive search time. The presence of large fish beneath the FAD's enabled handline fishing while drifting, thus reducing fuel consumption even more.

Along with the successes achieved by FAD fishing, there have been some negative developments. The FAD's did not last very long, nearly all users experienced substantial FAD losses, and conflicts among user groups have developed.

This report reviews the development of the FAD's in the Pacific and Indian Oceans, the results of fishing success, and the problems encountered in FAD fishing.

DEVELOPMENT OF FISH AGGREGATING DEVICES

The concept of using moored objects to attract fish is not new. Fishermen in the Philippines used payaos (bamboo rafts) prior to World War II to aggregate fish for handline fishing (de Jesus 1982), Japanese fishermen used moored bamboo rafts to attract dolphin, Coryphaena hippurus (Kojima 1960), Indonesian fishermen used anchored fish lures (coconut fronds) to attract carangids, mackerels, and clupeoid fishes (Soemarto 1960), and Maltese fishermen used moored cork-slabs to attract dolphin and pilotfish (Galea 1961). Several authors have attempted to explain the association of fish with floating objects. Gooding and Magnuson (1967) reviewed the hypotheses that have been advanced by others and listed the following explanations: (1) food collecting around the object attracted fish; (2) negative phototaxis in response to shadow cast by the object; (3) shelter from predators; and (4) use of the object as a spawning substrate. Hunter and Mitchell (1967) found little evidence to support the mechanisms postulated by others and suggested instead that pelagic fishes are attracted to drifting materials because the objects function as schooling companions, and for species not adapted to a pelagic life, the objects may function as substitutes for reef or other substrates.

Initially, FAD's consisted of simple rafts, with or without suspended materials, which increased the area for organisms to grow on and for small fish to seek shelter. The early FAD's were anchored in protected waters close to shore, but through the years, their use has extended into deeper waters and to open-ocean areas requiring sturdier construction. In the Philippines, the initial simple rafts, which consisted of bundles of bamboo, gradually evolved into single- and, eventually, double-layered bamboo rafts (de Jesus 1982), rafts of varied designs, such as the V-shaped raft described by Murdy (1980), and more recently to rafts made of steel. The double-layered bamboo raft, the type most commonly used at present, is approximately 2.5 m wide at one end, tapered at the other, and 12 m or more in length.[1] These rafts are widely used in the quiet waters of Moro Gulf and in the Sulu Sea off Palawan Island in depths ranging from 2,200 to 5,400 m. They evolved concurrently with the introduction of tuna purse seine fishing in the Philippines and with the rapid growth of the fishery. They have been extremely effective in aggregating fish and up to 200 metric tons (mt) of tunas have been caught in a single set of the purse seine around the rafts.

The rough open-ocean conditions in the central Pacific demanded FAD's that were sturdier than rafts made of bamboo. Developmental work (Matsumoto et al. 1981) at the Southwest Fisheries Center, Honolulu Laboratory (HL) resulted in a FAD fabricated with two 208-ℓ (55-gal) steel oil drums filled with polyurethane foam and held together in a frame of angle iron (Figure 1). The FAD's, anchored in depths of 400-2,300 m, aggregated

[1]Matsumoto, W. M. Payao fishing in the Philippines. Manuscr. in prep. Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812.

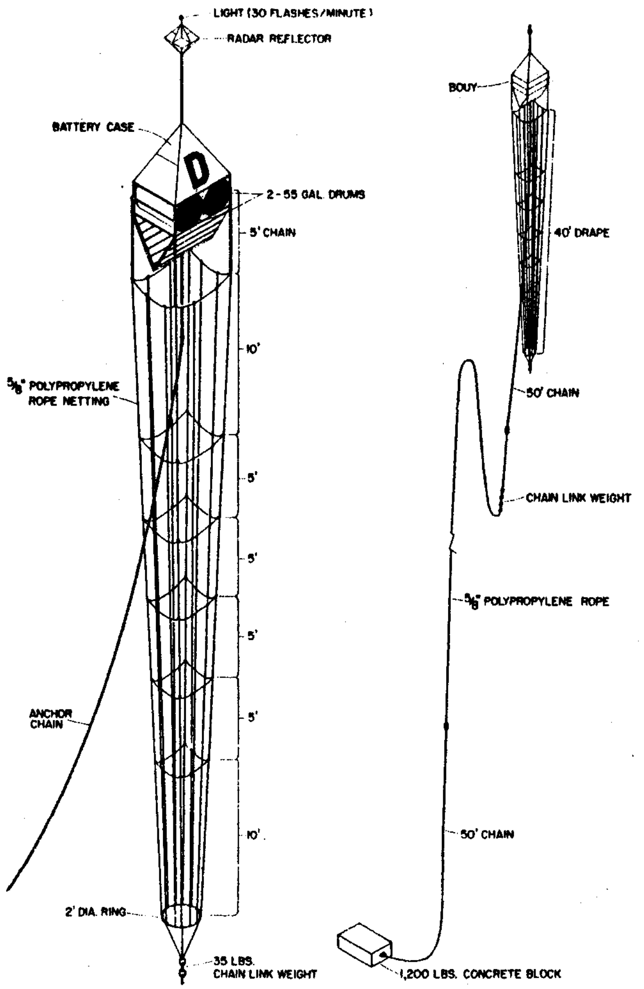

Figure 1.--Fish aggregating device, buoy type.

fish, mostly skipjack tuna, Katsuwonus pelamis, in sufficient quantities to permit commercial-scale fishing by pole-and-line vessels. As a result of the success of the HL experiment, the Hawaii Department of Land and Natural Resources (DLNR) initiated a full-scale FAD system, involving 26 FAD's made of large tractor tires filled with polyurethane foam, for the benefit of commercial and recreational fishermen in the State of Hawaii. Other Pacific island countries followed suit, using the HL and DLNR FAD's and other types of their own design.

RESULT

Distribution of fish aggregating devices.--Since 1979, 23 countries have either deployed or contemplated the deployment of FAD's within 6 to 12 months. The localities of deployment are shown in Figure 2. While the FAD's in most countries have been deployed to aid the local artisanal fisheries, commercial pole-and-line or purse seine vessels, have fished around them, particularly in Belau, Fiji, Hawaii, Papua New Guinea, and Western Samoa. Experimental FAD's installed over the Solomon Rise by the Japan Marine Fishery Resource Research Center (JAMARC) in November 1980 (Iwasa 1981) and in the eastern equatorial Pacific by the Inter-American Tropical Tuna Commission (IATTC) in April-November 1980[2] have been fished by purse seiners. In some countries, such as Western Samoa and Fiji, the FAD's have been subjected to fishing by both commercial pole-and-line and purse seine vessels.

Types of fish aggregating devices.--The types and number of FAD's used by the various countries and the number planned for deployment in the near future are summarized in Table 1. As of mid-1982 more than 379 FAD's have been deployed. Many have been lost and many of these have been replaced. In addition, more than 147 have been planned for fabrication or deployment by mid-1983.

The types of FAD's used have varied considerably due to the desire and necessity of some countries to utilize low cost materials that were available locally. The early users (American Samoa, Guam, Western Samoa) employed FAD's similar to that of the HL experiment. However, their FAD's had three instead of two oil drums (also of HL design) laid side to side and encased in a framework of angle iron. Each FAD had a superstructure supporting a radar reflector and an intermittently flashing marine warning light. A fish attractant, consisting of fish netting, cargo-net appendage made of large (16-mm) rope, strings of burlap bags and tire sidewalls, was suspended from the FAD to depths of about 20 m. The DLNR devised FAD's using old tractor tires with diameters of up to 2 m and filled with polyurethane foam. Guam and Belau also used tractor tire FAD's fashioned after the DLNR model. Other types of FAD's included rafts constructed from bamboo poles, fiberglass poles, plyboard, and pipe frames with steel drum as floats.

Second generation FAD's consisted of 3-m diameter doughnut shaped, fiberglass rings (American Samoa), twin- (and later) single-hulled, 1 x 2 m buoys constructed of 2.5 mm aluminum sheeting (Western Samoa), and a cluster of five 71-cm steel spheres welded together to form a buoy approximately 2 m in diameter (DLNR). All FAD's were equipped with radar reflector and light above and fish attracting appendage below. In some cases the latter consisted of 1-2 m plastic binding strips attached directly to the anchor line or to strands of rope hung from the FAD.

The FAD user groups differed by locality. In most Pacific islands where fishing has been done on the artisanal or subsistence level, trolling and handline fishing are done from small outboard motor-powered crafts. In countries where diesel-powered fishing vessels are used, such as the Philippines, United States (Hawaii), Western Samoa, and Belau, or in those countries that have entered into fishing agreements with Japanese or New Zealand fishing companies in their territorial

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[2]Guillen, R., and D. A. Bratten. 1981. Anchored raft experiment to aggregate tunas in the eastern Pacific Ocean. Inter-Am. Trop. Tuna Comm., Internal Rep. No. 14, 10 p.

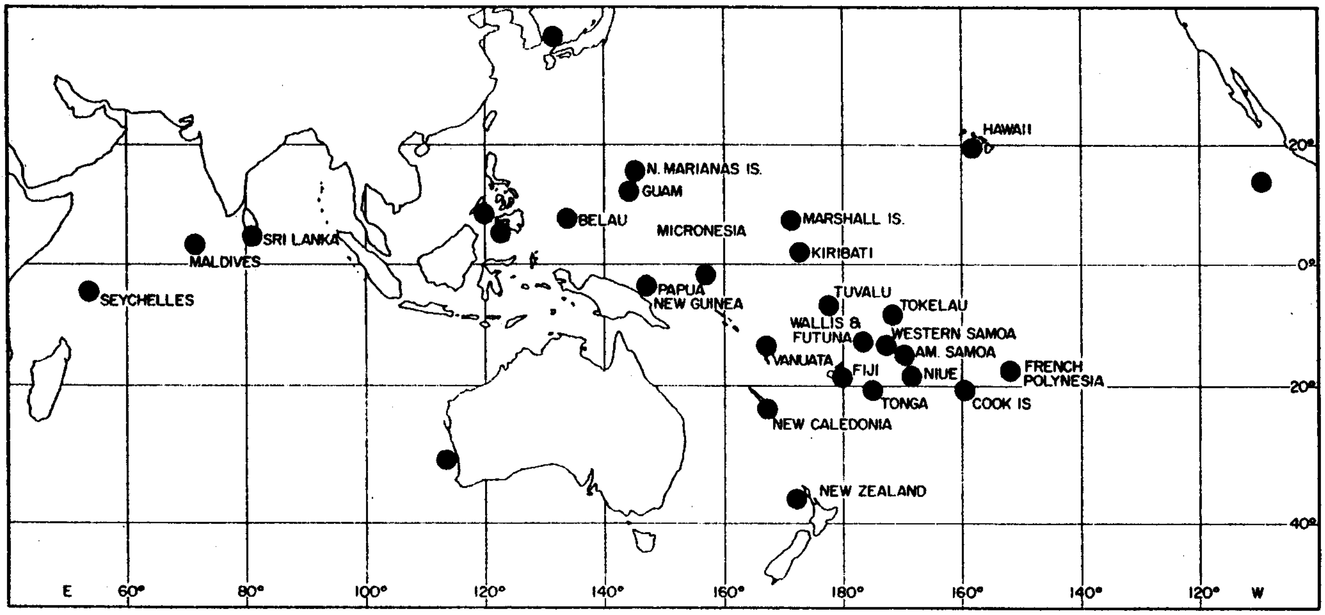

Figure 2.--Locations where fish aggregating devices have been deployed, 1979-81, or where deployment is planned in the Pacific and Indian Oceans.

waters, such as, Fiji, Belau, and Papua New Guinea, fishing on a commercial scale is being done either by pole and line, purse seine, or both. Recreational or sport fishing is done mainly in Hawaii, where fishing is generally done by trolling and often with handlines, particularly by trailer-boat fishermen.

Catch.--Regardless of the type of FAD's used, the results were the same in all countries. The FAD's attracted fish in great numbers leading to increased catches. Although accurate catch data are not available, owing to reluctance of the fishermen to file catch reports, replies to our questionnaires from a number of countries disclose the effectiveness of the FAD's. In Kiribati skipjack tuna appeared around the FAD's in 9 days and catches increased from 100 to 250 kg/day/boat. Small (7-10 kg) yellowfin tuna, *Thunnus albacares*, were taken on handlines after 20 days. In the Cook Islands evidence of the effect of the FAD's was indicated in the lowering of the retail price of fish from \$3.96/kg to \$1.87-\$2.20/kg. In Western Samoa the average catch of tunas by *alias* (small outboard powered crafts) was 100 kg, with individual boats often experiencing catches of up to 500 kg in 1 h of fishing at daybreak. From prior correspondence (A. L. Philipp, Chief, Fisheries Division, Government of Western Samoa), we learned that a commercial purse seiner had made a set on an estimated 20 mt of skipjack tuna at one of the FAD's. In Fiji catches by purse seiners have been as high as 55 mt in a single set around the FAD's, and commercial pole-and-line vessels have averaged 6 mt/day, compared to 1 mt/day prior to the installation of FAD's. In Hawaii the DLNR reported that 3,607 FAD visits by commercial and recreational fishermen during April 1980-April 1982 resulted in 400 mt of fish, and averaged 111 kg/visit.

The most detailed catch records of fishing around FAD's in the Pacific were those obtained during the experimental study in Hawaii (Matsumoto et al. 1981). In 1978 commercial pole-and-line vessels visited the FAD's 247 times and caught 523 mt (1,153,900 lb) of tunas, with an average of 2.13 mt (4,690 lb)/visit (Table 2). During the months of high catches, 193 mt in April and 196 mt in May, individual boat catches of more than 4.5 mt were made on 23 visits, catches of more than 9.0 mt on 2 visits, and catches of more than 13.6 mt on 2 visits. Recreational and commercial trolling boats caught an additional 7.3 mt of fish. The FAD's attracted tunas of all sizes ranging from below 1 kg to over 45 kg. Small tunas below 2 kg generally remained in the immediate vicinity of the FAD's, whereas the larger skipjack and yellowfin tunas roamed over wider areas from 4 to 5 km or more during the day. These fish apparently returned to the FAD's at night since the day's first catches were invariably made at the FAD's at daybreak and the fishing vessels moved away from the FAD's after sunrise, while continuously fishing the same school. Medium-sized (13-45 kg) yellowfin tuna were caught on baited lines either by deep-trolling at reduced speed or by handlining while adrift. These fish were caught anywhere within 1.6 km of the FAD's. Other fish such as marlin and spearfish were usually taken by trollers at distances of up to 2.4 km, whereas dolphin were usually taken well within 30 m of the FAD's and up to 8 km away.

The greatest aggregation of fish yet to be seen under a DNLR FAD was a school of large (55-70 kg) yellowfin tuna (R. E. Brock, University of Hawaii, Honolulu, Hawaii, pers. commun.). The school, estimated at about 1,600 mt, appeared around a FAD that had been deployed for more than 180 days.

Table 1.--Deployment and longevity of fish aggregating devices in the Pacific and Indian Oceans, 1979-81.[1]

Country or locality	Type of fish aggregating device	No. set (planned)		No. lost	Fish aggregating device (days) Range	Mean	Max.	Continuing[2]
American Samoa	3-drum	11		11	7-510	266.0	510	No
	Doughnut	5	(8)	3	14-60	35.0	250	Yes
Australia	3-drum	4		4	335-427	365.5	427	No
	Foam block	2	(6)	--	--	--	120	Yes
Cook Islands	3-drum	1		1	150	--	150	No
	Aluminum catamaran	4	(2)	--	227-592	--	592	Yes
Eastern Pacific	Plyboard raft	5		5	62-137	107.3	137	No
Fiji	Bamboo raft	120		96	1 year	--	--	--
	Wooden raft	2		1	--	--	120	--
	Aluminum catamaran	1		--	--	--	--	--
French Polynesia	3-drum	8		4	--	--	--	--
Guam	3-drum	3		3	6-123	70.3	123	No
	Tractor tire	5		3	28-258	142.6	338	Yes
Hawaii	Tractor tire	26		11	60-540	237.3	540	No[3]
	Pentasphere	34	(45)	25	30-450	164.4	450	No
Kiribati	Fiberglass-pole raft	3	(6)	3	7-40	25.0	40	No
Maldive Islands	Various types	9		--	--	--	--	--
Marshall Islands	Bamboo raft		(20)	--	--	--	--	--
Micronesia	--	20+		--	--	--	--	--
New Caledonia	--		(6)	--	--	--	--	--
New Zealand	--	3		--	--	--	--	--
Niue	Aluminum single hull		(2)	--	--	--	--	--
Northern Marianas	3-drum	5		5	150-310	162.0	210	No
Belau	Tractor tire	6		6	30-270	150.0	270	No
Papua New Guinea	Bamboo raft	76		25	--	--	--	--
Seychelles	Pipe-frame raft	5	(10)	1	60	--	123	Yes
Sri Lanka	--		(12)	--	--	--	--	--
Tokelau	--		(1)	--	--	--	--	--
Tonga	Aluminum catamaran	2	(2)	2	30-210	120.0	210	No
Tuvalu	--		(NA)	--	--	--	--	--
Vanuatu	Plyboard raft		(5)	--	--	--	--	--
Wallis and Futuna	--		(5)	--	--	--	--	--
Western Samoa	3-drum	5		5	236-270	257.4	270	No
	Aluminum catamaran	23	(3)	10	287-424	368.2	566	Yes
	Total/range	379+	(147)	224			40-592	

[1]Exclusive of countries that used FAD's prior to 1979.
[2]Maximum FAD life continuing as of April 1982.
[3]Maximum FAD life continuing as of June 1982. All existing tire type FAD's removed and replaced by pentasphere type.

Table 2.--Fish species caught (in pounds) by pole-and-line fishing in 1978 during the Hawaiian fish aggregating device experiment (Matsumoto et al. 1981).

		Species									
		Skipjack tuna		Yellowfin tuna		Kawakawa		Dolphin		Totals	
Buoy	Visits	Catch	Catch per visit	Catch	Catch per visit	Catch	Catch per visit	Catch	Catch per visit	Catch	Catch per visit
A	92	357,044	3,880.3	22,682	246.5	1,479	16.0	854	9.3	382,031	4,152.5
B	1	5,110	5,110.0	0	0.0	0	0.0	0	0.0	5,110	5,110.0
C	14	103,037	7,359.8	1,475	105.4	4,218	301.3	0	0.0	108,730	7,766.4
D	139	573,106	4,123.1	80,183	576.9	1,706	12.3	3,034	22.6	658,029	4,734.0
Total	246	1,038,297	4,220.7	104,340	424.1	7,403	30.0	3,888	15.8	1,153,900	4,690.6
Percent of total catch		89.73		9,28		0.64		0.34		99.99	

Species of fish caught.--Various species of fish aggregate around floating devices. In the Hawaiian experiment Matsumoto et al. (1981) reported that trolling vessels caught 12 species of fish: skipjack tuna; yellowfin tuna; bigeye tuna, *Thunnus obesus*; kawakawa, *Euthynnus affinis*; dolphin; wahoo, *Acanthocybium solandri*; blue marlin, *Makaira nigricans*; striped marlin, *Tetrapturus audax*; shortbill spearfish, *T. angustirostris*; rainbow runner, *Elagatis bipinnulata*; greater amberjack, *Seriola dumerili*; and barracuda, *Sphyraena argentea*. Underwater observations disclosed other species normally not taken by pole and line or trolling gear. These included such species as sea chub, *Kyphosus cinerascens*, scrawled filefish, *Alutera scriptus*, rough triggerfish, *Canthidermis maculatus*, mackerel scad, *Decapterus pinnulatus*, pilotfish, *Naucrates ductor*, freckled driftfish, *Psenes cyanophrys*, and juveniles of many species. Sharks and porpoises were frequent visitors around the FAD's. Other studies on drifting objects list even greater numbers of fish species: Hunter and Mitchell (1967) listed 32 species and Gooding and Magnuson (1967) listed 35. The kinds of fish found under drifting objects depend largely upon the species naturally occurring in the vicinity where the object is placed and therefore could vary from one locality to another.

Impact of fish aggregating devices.--The success of FAD fishing has had obvious impact wherever FAD's have been used. In the Cook Islands it has led to the construction of a fish marketing establishment and, as noted above, has resulted in reducing the cost of fish to the consumer by nearly 50%. In Western Samoa, the increased catches of tunas have led the Western Samoans to explore the possibility of exporting the excess tuna catches to the canneries in American Samoa. In Hawaii, the growth of the handline fishery for medium to large (23 to over 90 kg) yellowfin tuna has resulted in increased direct shipments to the west coast and midwestern cities of the continental U.S. Other benefits also have been realized from FAD fishing. In Western Samoa records of a diesel-powered, pole-and-line vessel indicated a reduction of fuel usage from an average of 443 to 69 ℓ/day and an increase of tuna catches from 310 to 613 kg/day (A. L. Philipp, pers. commun.).

PROBLEMS ENCOUNTERED

Despite the successes achieved, FAD fishing has not been without its problems. The cost of construction and mooring, the relatively short lifespan, and the numerous losses suffered have all added greatly to the total cost of installing and maintaining the FAD's. To many island nations in the Pacific and Indian Oceans, these costs have been high relative to the scale of their economic resources.

Longevity.--For the most part FAD life has been relatively short, ranging from 6 to 592 days (Table 1), and has varied according to the type of construction. The FAD's built of fragile material or those that were bound with rope, such as plyboard, bamboo, and fiberglass-pole rafts, were relatively short lasting. Most of these broke apart well within 1 year. The FAD's made of more durable material and sturdier construction, such as oil drums, tractor tires, and steel spheres and aluminum-hull buoys, have lasted the longest (maximum durations of 510-592 days). Some of these, the aluminum catamaran types of the Cook Islands and Western Samoa with a reported maximum life of 592 and 566 days, respectively, were still in use as of April 1982. The maximum life of the tractor-tire type in Hawaii would have exceeded 540 days had it not been removed intentionally to be replaced with the newer pentasphere type.

Cost.--The per unit cost of FAD's has varied among countries, depending upon the type of FAD constructed, the proportion of in-house labor contributed, the amount of materials acquired without cost, the depth of mooring, and the cost of deployment (Table 3). In the replies to our

Table 3.--Summary of fish aggregating device costs.

Country	FAD type	Cost per fish aggregating device: Deployment depth (m)[1]	FAD only	FAD and mooring	Deploy-ment	Total
American Samoa	3-drum	900-2,500	$600	$2,400	[2]Nil	$2,400
	Doughnut	900-2,500	--	3,000	$ 600	3,600
Australia	3-drum	145-183	--	3,200	1,000	4,200
	Foam block	145-183	--	1,400	1,500	2,900
Cook Islands	Aluminum catamaran	1,097-1,463	860	2,770	150	2,920
Fiji	Aluminum catamaran	NA	860	2,930	[2]Nil	2,930
	Box raft	NA	27	2,090	[2]Nil	2,090
	Bamboo raft	NA	--	780	[2]Nil	780
Guam	3-drum	550-1,830	--	2,740	[2]Nil	2,740
	Tractor tire (A)	550-1,830	--	2,500	[2]Nil	2,500
	Tractor tire (B)	550-1,830	--	3,900	630	4,530
Hawaii	Tractor tire	228-2,930	--	2,500	2,000	4,500
	Pentasphere	228-2,930	--	2,500	2,000	4,500
Kiribati	Fiberglass-pole raft	145-183	--	500	100	600
Belau	Tractor tire	1,100-3,700	--	3,340	240	3,580
Seychelles	Pipe-frame raft	900-1,800	--	1,500	[2]Nil	1,500
Tonga	Aluminum catamaran	1,097-1,463	860	2,695	25	2,720
Western Samoa	3-drum	1,480-2,835	600	2,400	[2]Nil	2,400
	Aluminum catamaran	1,480-2,835	860	2,800	200	3,000
				Mean = $2,418		Mean = $2,993

[1]Cost of average mooring depth.
[2]Deployed by government or fishing company vessels at no charge.

questionnaire the cost of the FAD was generally reported together with the cost of the mooring system (anchor, anchor line, and other hardware). Cost figures of $600 (all cost figures are given in U.S. dollars) specifically for FAD construction were available only for the three-drum type initially used in American Samoa and Western Samoa--since these units had been constructed under contract in American Samoa--and for the aluminum catamaran type ($860) which had been fabricated in Western Samoa and purchased by several countries. The actual cost of the tractor-tire type was difficult to determine since the large items, such as tires, anchors, and chain had been acquired at no cost or at nominal fees from private firms, government supply, or government surplus sources.

The combined cost of the FAD and mooring system provided by the respondents varied considerably from $500-$780 for simple rafts to $1,400-$3,340 for the more labor-intensive types, depending on the mooring depth, line scope, and size of rope used. The average combined cost was $2,418/FAD. The mooring system costs for FAD's deployed in depths greater than 900 m comprised more than two-thirds of the combined costs. Estimates of mooring-system costs alone were $1,800 in American Samoa (16-mm polypropylene rope, average mooring depth of 1,417 m) and $1,940 in Western Samoa (16-mm polypropylene rope, average depth 1,930 m), and $1,910 in the Cook Islands (19-mm polypropylene rope, average depth 1,259 m) and $1,835 in Tonga (19-mm polypropylene rope, average depth 1,259 m). A rough estimate of mooring cost relative to depth is $50/100 m of line (16-mm polypropylene rope) plus $1,000-$1,200 for the anchor and hardware, consisting of a 1,000-kg concrete block anchor, 60 m of 13-mm chain, and galvanized connecting hardware. The cost increases proportionately with larger rope, with rope made of other synthetic fibers, or with better quality swivels.

In addition to these, the cost of deployment added significantly to the total cost in some countries. Deployment cost varied greatly from nil to $2,000 each depending upon the size of vessel used and the charter rates in each locality. Most countries with no reported deployment cost had their FAD's deployed by government-owned vessels or, as in the case of Fiji, bamboo rafts were fabricated and deployed by foreign fishing companies for their own use. The total cost of the FAD's, including construction, mooring system, and deployment, ranged from $600 to $4,530, and averaged $2,993/unit.

Added to the initial cost were other costs such as those incurred in maintaining the deployed units and replacing lost FAD's. These costs varied by country depending upon vessel charter costs, the longevity of the FAD's, and the frequency of losses. In some localities, such as Guam, Hawaii, and Western Samoa, there were as many as two replacements at a FAD site within 2 years.

<u>Losses of fish aggregating devices</u>.--The losses of FAD's have been high during the more than 3 years they have been in use in the Pacific and Indian Oceans. These can be grouped into three categories by FAD types: (1) Rafts made of bamboo, plyboard, and fiberglass poles; (2) FAD's made of steel frame and supports, including the oil drum, tractor tire, pentasphere, aluminum catamaran, and pipe-frame raft types; and (3) FAD's made of foam blocks. In the first category, losses have ranged from 63 to 100%, due mostly to the disintegration of the rafts. One fiberglass-pole raft was reported vandalized and the poles stolen. In the second category losses varied from 40-42.3% for the aluminum catamaran and tractor-tire types to 73.5-89.2% for the pentasphere and oil-drum types. These types were the longest lasting with maximum durations of 427-592 days. The heavy losses suffered by the oil-drum type were in part due to high wind resistance, since they contained a large canopy above the waterline. It is too early to judge the merits of the foam-block type, since these were installed as recently as December 1981. The FAD losses for all types were extremely high at 59.1%.

It is difficult to determine the exact cause of FAD losses, since most of the FAD's that had broken loose from the moorings have not been recovered. The few recoveries to date (20) and onsite observations have provided some clues as to the probable causes, which are given below.

Item	Known or probable cause	Number	Percent
1.	Raft breakage	96	61.5
2.	Mooring line failure	35	22.4
3.	Line break by vessels	7	4.5
4.	Unfavorable mooring site	6	3.8
5.	Storm	4	2.5
6.	Vandalism	3	1.9
7.	Sinking	2+	1.3
8.	Fish bite (shark)	1	0.6
9.	Inadequate anchor	1	0.6
10.	Entangled by whale	1	0.6
		156+	

In addition to these, 68 losses were of undetermined causes. The losses caused by Item 1 were due almost entirely to breakup of bamboo rafts. Bamboo poles tied together with cordage apparently were too fragile in open-ocean conditions. Losses due to line failure (Item 2) were caused by such things as inadequate rope splices, loosened shackle pins, and rope breaks caused by twisting (insufficient or poor quality swivels). Of these the most prevalent cause was attributed to rope splice failures. To facilitate the handling of the bulky lines which were as much as 2 miles long, most users purchased rope in coils of 183 or 365 m (600 or 1,200 ft). Connecting these coils of rope together involved numerous splices, both between coils and at rope ends linking up to swivels and chain sections. Thus, a mooring at 1,000 m, consisting of 1,400 m (line scope of 1:1.4) of rope and a midwarp weight, required as many as 10 splices. A midwarp weight to keep the excess line from surfacing during changes in tidal currents was necessary because of the buoyant polypropylene rope. Splicing methods between coil sections varied; some were single splices with as few as 7 tucks, some with 14 tucks or more, and a few with double splices, in which the rope ends were overlapped by 2 m or more and each end then spliced into the opposing rope. Line failure due to loosened shackle was noted in one instance. Loss of FAD's due to line breaks caused by vessels (Item 3) included such mishaps as the severing of the line by the propellers of fishing boats or passing ships, where the excess line had floated to the surface, and the severing of the lines by a tugboat towing cable. The latter incident occurred twice. Unfavorable mooring sites (Item 4) included deployment of FAD's at less than half the depth for which the lines had been prepared and setting the anchor on top of pinnacles or in narrow gorges with steep sides. These resulted in the line chafing on the bottom at the midwarp weight, submerging of the FAD as the anchor was pulled off the pinnacle or line chafing against the sides of the gorges. Vandalism (Item 6) consisted of the actual dismantling of a fiberglass-pole raft to remove the poles and overloading the anchor line by too many boats tying up to the FAD. During the experimental phase in Hawaiian waters, such incidents as severing the anchor line intentionally by irate fishermen whose fishing line (handline) had snagged on the anchor line was experienced. Sinking of the FAD (Item 7) occurred with the oil-drum type when leaks in the drum caused the foam to disintegrate, resulting in the loss of buoyancy.

Considering only those FAD's constructed of material more durable than wood or bamboo rafts and intended for long-term use, losses resulting from mooring line failures, line breaks caused by vessel propellers, unsuitable mooring sites, sinking, and inadequate anchor (Items 2, 3, 4, 7, and 9) account for 85% of the losses. All these causes involved human error, and, as such, they can be remedied and the losses reduced. Much of this can be done by eliminating or reducing the size of the high wind-resistant canopy in the oil-drum type, using uncorrodable oil drums, treating the drums to retard corrosion, replacing heavy and massive fish-attracting pendants with pendants made of plastic binding strips attached to individually weighted ropes to reduce drag, and being especially careful in fabricating the mooring lines. In this respect we note that the University of Hawaii Sea Grant Program, the South Pacific Commission, and others have initiated studies or are considering engineering evaluations of FAD's with the intention of minimizing FAD losses.

User conflict.--The large aggregations of fish collecting around FAD's have attracted a wide mixture of fishermen (subsistence level, recreational, recreational-commercial, and commercial) utilizing various fishing gear and methods (such as handlines, surface trolling, deep trolling at reduced speeds, pole and line with live-bait chumming, and purse seining), and an assortment of fishing boats ranging in size from outboard-powered canoes and skiffs to diesel-powered bait boats and seiners. This mixture has resulted in conflicts among FAD users. Small-boat fishermen complain that the larger vessels with large-scale fishing capabilities will deplete fish around FAD's, and the larger vessel fishermen complain that small boats clutter the area and interfere with their fishing operations. In Fiji, conflicts have arisen between the two commercial user groups; pole-and-line fishermen accuse the purse seiners of completely fishing out the FAD's and both groups accuse each other of raiding their FAD's.

Conflicts between large-scale tuna fishermen and small-boat operators can be alleviated to some extent by a system of allocating FAD's nearshore to small boats and offshore FAD's to larger commercial vessels. Similarly, some method of allocation needs to be devised to minimize conflicts between pole-and-line and purse seine vessels.

SUMMARY

1. The experimental use of FAD's constructed to withstand rough, ocean conditions in Hawaii, has led to a tremendous surge in FAD fishing in other areas. To date 20 countries in the Pacific and 3 in the Indian Ocean have either deployed or were planning to install FAD's in their waters.

2. The types of FAD's used have varied considerably among countries. These included FAD's made of oil drums filled with foam and encased in a metal frame, large (2-m diameter) tractor tires filled with foam, rafts made of bamboo poles, fiberglass poles, plyboard, and pipe frames with oil drums as floats, 3-m diameter, doughnut shaped, fiberglass ring, and completely enclosed catamaran and single-hulled buoys made of aluminum and filled with foam.

3. The FAD's have been extremely successful in aggregating fish wherever they have been used and have increased fish catches by twofold or threefold. This has resulted in a reduction of the retail price of fish by nearly 50% in some countries and a significant savings in fuel costs.

4. The per unit cost of the FAD and mooring system ranged from $500 for simple rafts to over $3,000 for the more labor-intensive types, with two-thirds of the cost attributed to the mooring line in FAD's deployed at depths greater than 900 m. The total costs were much higher for those countries that had to rely upon private vessel charters to deploy the FAD's. For these, total costs were increased by up to $2,000/FAD.

5. Of the 379 FAD's deployed since 1979, 224 were reported lost, some within 1 week after deployment. The longest lasting FAD is still operating after 592 days as of April 1982. Mooring line failures, line breaks caused by vessel propellers, mooring in unsuitable bottom, sinking, and inadequate anchor comprised 85% of the losses among FAD's that were intended for long-term use.

6. The success of the FAD's in attracting fish in large quantities has led to conflicts among user groups. These conflicts can be alleviated to some extent by a workable system of allocating FAD usage.

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